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Optimal supplier testing and tolerance strategies for genetically modified (GM) wheat

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Abstract

A stochastic optimization model was developed to determine optimal testing strategies, costs, and risks for dual marketing of genetically modified (GM) and non-GM wheat in an export supply chain. The optimal testing strategy is derived that minimizes disutility of additional system costs due to testing and quality loss. Cost components were estimated including those related to testing, quality loss, and a risk premium to induce shippers to undertake dual marketing as opposed to handling only non-GM crops. Uncertainties were incorporated for adventitious presence and commingling, variety declaration, and test accuracy. Sensitivities were performed for effects of variety risks and declaration, penalty differentials, buyer tolerances, risk aversion, and GM adoption. Results indicate testing and segregation can be performed at a relatively low cost and risk to buyers.

JEL classifications: Q13, Q17

Keywords: Segregation; Testing; Tolerance; Genetically modified; Wheat; Risk premium

1. Introduction

Biotech grains and oilseeds have become increasingly pervasive because of their potential to provide agronomic benefits to producers and attributes important to end users. Genetically modified (GM) wheat traits are under development and may be available by 2009 (Wilson et al., 2003). Concurrently, European Union (EU) proposals with respect to tolerances will have a major impact on commercialization decisions of some GM wheat traits. The EU proposals require national governments to establish regulations subject to guidelines (Elliot, 2004). Development of testing, tolerance, and segregation strategies are imperative to firms throughout the production and marketing supply chain to facilitate the dual marketing of GM and non-GM grains. Testing and segregation strategies will need to be adopted to detect GM content in non-GM shipments and conform to specification limits, which are expected to vary across buyers.

Some studies have quantified some of these costs, but the risks to both buyers and sellers are also important. Buyer risk is the probability of receiving a detectable level of GM content above specifications in a shipment identified as non-GM. Seller risk is the probability that a shipment thought to be non-GM is rejected due to GM adventitious presence exceeding buyer specifications. A stochastic optimization model of the grain export supply chain marketing GM and non-GM grains is developed in this article. The model jointly determines optimal test locations, intensities, and supplier tolerances given buyer tolerance limits on GM content.

At the time this research was being conducted, prospective GM wheat traits included Monsanto Roundup Ready (RRW), Syngenta's fusarium resistance, and others including varying forms of protein enhancements and drought resistance (Wilson et al., 2003). Since then, Monsanto withdrew its RRW due to consumer opposition and lack of support by producer groups. Though the analysis presented here uses the RRW trait, the framework, qualitative results, and model are applicable to the other anticipated traits in wheat as well as to other grains.

There are two contributions of this study to the evolving literature on marketing GM crops. One is that it jointly determines the internal supplier tolerance as a component of the optimal testing strategy (where to test, how intensively to test, and the type of test to apply) to conform to the buyers' tolerance. Buyers

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specify tolerance in the purchase contract and suppliers then choose where to test, the test tolerance, and intensity of testing to meet the buyers' tolerance. Suppliers normally would choose a strategy that would have a tighter tolerance than the buyers due to risks arising from sampling, test accuracy, and adventitious commingling. Incorporation of a Taguchi loss function and the probability of adventitious presence within the model allow for differentiation between effects of testing and quality loss costs when determining the optimal test strategy. Second, the results illustrate how increases in GM adoption raise these costs and risks, and limit the prospect of conforming to buyer tolerance limits.

2. Background and previous studies

There are many studies related to the problem addressed here. To summarize these, we first delineate the differences among identity preservation (IP), testing, and segregation and traceability. Then, we summarize studies that address risk in GM handling models and the use of the Taguchi loss function to interpret the role of tolerance.

2.1. Segregation, IP, and traceability

These are frequently used interchangeably but they differ. Segregation is the isolation of products with similar attributes. Unlike IP, the identity of the grain is not preserved. Segregation is common in many grains and is evolving in response to the dichotomy in international market acceptance of GM crops. Segregation has been a long-standing practice in other differentiated grains including wheat (which is segregated by numerous traits including protein, test weight, grade factors, falling numbers, vomitoxin, dockage, and more recently in selected functional traits) and malting barley (segregated by grade factors, germination, variety, vomitoxin, etc.). In these systems, while lots of different varieties or attributes are kept separate, they may be blended with other lots of similar varieties/qualities as they are aggregated and move through the grain handling system. Testing is a prerequisite to segregation and occurs throughout the supply chain.

IP differs in that it allows the source of grains to be identified and retained as it moves through the supply chain (Buckwell et al., 1998). Although there are a number of definitions of IP, one widely used is that it "refers to a system of crop management which preserves the identity of the source or nature of materials" (Glaudemans, 2001). IP is stricter than segregation because of requirements of physical barriers to prevent commingling and prescribed production practices (Golan et al., 2004), but it is particularly important for products with high consumer-aversion to GM ingredients. The additional costs for IP include production, storage, handling, and logistics (Kalaitzandonakes et al., 2001; McDonald et al., 2004). An important step in IP is on-farm segregation and use of buffer strips, certified seed, and other costs associated with certification. In addition, indirect or hidden costs emerge by the underutilization of commodities production, storage, and transport (Kalaitzandonakes, 2004). Operational changes, such as use of sealed bins, additional cleaning of pollen and grain residue, dedicated delivery dates, and insurance or noncompliance penalties, add extra costs to IP. The added costs of these IP systems vary substantially depending on what was included, but generally range from 16 to 54 c/bu (see Directorate-General for Agriculture, European Commission, 2002, and Wilson and Dahl, 2005, who each summarize these studies).

Traceability differs because of the need to trace the crop from the field to the consumer and the need to provide informational flows among market participants. Traceability has been a common marketing practice for intra-EU trade in grains and oilseeds for many years, and there are numerous organizations that have developed elaborate systems to conform to these needs (e.g., Agricultural Industries Confederation, 2005; Assured Combinable Crops, 2005, which are each quality assurance schemes used in the United Kingdom). It is also being used extensively in the livestock sector (Hobbs, 2004). Traceability is now also part of the official EU regulations on imported grains that may contain GM and is a component of their labeling regulations, and South Korea recently has adopted traceability for imported grains (non-GM Report, 2005). Varying forms of traceability exist and are being developed to conform to EU trade requirements and encompass elements of IP in addition to certification and establishment of paper trails (Farm Foundation, 2004; Golan et al., 2004). Important requirements of the EU traceability system are the need to transfer information about the product among parties, retention of such information for five years, and certification. Finally, costs increase as a result of traceability costs (Golan et al., 2004). However, to our knowledge, cost estimates of these systems have not been published, but it is expected that IP and traceability systems will involve more costs since they are more comprehensive.

These are competing systems and their use depends in part on the regulatory and competitive environment in each country. The EU has adapted traceability as a key component of marketing, and recent regulations require like systems be in place for imported grains. IP is also used in some transactions for wheat exports from North America to the EU (Kennett et al., 1998). IP is used to a lesser extent within other countries. The marketing of GM grains and oilseeds from North America and the United States has resulted in an escalation of testing and segregation as GM averse countries seek efficient ways to conform to their requirements. Most of these involve some type of third party testing and certification. It is important that the choice among these is largely the buyers' prerogative and governed by their regulatory and competitive environment. Consequently, it is expected that there will be a wide range of applications across importing countries and grains. Indeed, the diversity of traceability systems has resulted in a lack of standard practices and protocols across these systems (Hobbs, 2004).

2.2. Risks in testing, certification, and handling

There are risks of compliance and certification, because tests and procedures for biotechnology are imperfect, take time to perform, and add costs. A few studies have quantified risks of adventitious commingling in handling. Ingles et al. (2003) analyze residual and cross-contamination of grain during handling to address the imminent evolvement of segregation strategies to segment GM and non-GM grain to meet stringent thresholds. Their results indicate that after switching segregations, only the first 15–20 bushels of grain handled were contaminated at a level greater than 1% and only the first 40–50 bushels of grain were contaminated at a level greater than 0.5%. Conformance to rigorous tolerance limits is attainable through pragmatic clean-out procedures.

Typically, the first testing point is at the country elevator (CE) to detect the presence of GM grain (Johnson and Lin, 2005), but testing can be conducted at any or all points of the vertical market system. Testing intensity depends upon the number of GM events that have to be detected either quantitatively or qualitatively through an array of testing methodologies including herbicide tolerance bioassay, immuno assay (which encompasses enzyme linked immunosorbant assay [ELISA] and strip test), and polymerase chain reaction (PCR). Selection of an appropriate testing technology is contingent upon the number of events to detect, time constraints, sample size, and tolerance.

2.3. Tolerances and Taguchi loss functions

Tolerances play an important role in the determination of an optimal testing strategy to mitigate the risk of nonconformance. Wu et al. (1988) define tolerance as the maximum deviation from a nominal specification within which the lot is still acceptable, and Irianto (1996) refers to tolerance as a specification limit. It is important to distinguish between buyer and seller tolerances. A buyer tolerance in a purchase contract indicates the level at which a lot could be rejected. The supplier would determine their own tolerance and testing strategy to conform to the buyers' tolerance. Normally, the supplier would target a tighter tolerance than the buyers' due to the risks involved throughout the system as a means of assuring conformance to the buyer tolerance. In this study, we determine the optimal supplier tolerance and testing strategy.

A tighter tolerance leads to higher costs (Irianto, 1996; Jeang, 1994; Wu et al., 1998). An optimal tolerance ultimately depends on "out of contract costs." This implies that as nonconformance costs escalate, more rigorous approaches to sampling, testing, and certifying should be adopted. Hence, Wu et al. (1998) propose a method whereby quality loss and cost are taken into account simultaneously to define an optimal tolerance for both symmetric and asymmetric loss functions.

Quality loss is due to deviations from a target value. The Taguchi loss function is used to quantify the cost of quality loss (D'Errico and Zaino, Jr., 1988). Even small deviations from the target value have quality costs, which continue to increase beyond the point at which lots are rejected. This is realistic as buyers who receive lots at or near specification limits would view them less favorably than lots that contain no GM. Use of the Taguchi loss function allows for differentiation of supplier strategies even when GM content is within buyer tolerances.

An asymmetric Taguchi loss function (only positive deviations from the target are considered) was used as negative values for GM content are not allowed. A target value of zero is indicated as nil GM content is preferred. Since deviations for grain within the non-GM flow represents multiple items, the Taguchi loss function used is specified as: $L = (A_O/\Delta_O{}^2)\cdot s^2$, where Δ_O is the upper tolerance limit (this is the level at which the buyer would reject the lot, or buyer tolerance), A_O is the loss at the upper tolerance, and s^2 is the variance of GM lot concentration for grain within the non-GM flow. This variance for GM lot concentration can be calculated by averaging the variance for all bushels within the delivered flow (Taguchi, 1986, pp. 121–122). The objective is to minimize total cost composed of additional system testing costs (all supply chain points), plus the quality loss of nonconformance to a target value of zero GM lot concentration. This allows for tradeoffs between testing and quality loss costs when jointly determining the supplier's testing/tolerance strategy to meet buyer specifications.

3. Empirical model

In our model, the buyer tolerance is given and we determine the optimal supplier tolerance and testing strategy. A system cost function for a vertically integrated exporter is specified and solved to maximize utility. This is equivalent to minimizing the disutility of additional system costs consisting of testing and quality loss at each marketing function and a risk premium for the handler due to their greater risks. The model is that of a vertically integrated firm, performing supply chain functions including CE receiving and loading, export elevator (EE) receiving and loading, and importing. Tests can be applied at any of these functions with varying intensities and tolerances and, if rejected, grain is diverted to the GM channel. Uncertainty in the model exists due to commingling which can occur at numerous locations within the supply chain with given probabilities, due to effects of sampling and test accuracies, and due to variability in the value of rejection costs at the upper tolerance limit (A_0) and grower truth telling. A more simple version of this model is used in Wilson and Dahl (2005) but excludes the simultaneity of testing decisions. Wilson and Dahl (2006) analyze the unique features of the Canadian wheat industry using a related specification.

The model simultaneously determines the optimal testing strategy including where to test, how intensively to test, and at what tolerance to test in the dual marketing of non-GM and GM grain flows. The model includes a risk premium to compensate for the additional risk in the dual GM/non-GM system over the risk in a non-GM system. We define the cost functions for each segregation including the Taguchi loss function below and in the next section and describe the model and risk premium estimation.

The additional system costs are composed of testing, quality loss, and risk premium. Testing costs are summed across functions and depend on where tests are conducted, at what tolerance tests are conducted, and how intensive are the tests at each location. Costs for tests vary depending on the technology utilized and the tolerance. Tests are assumed to utilize strip tests at intermediate points (i.e., CE, EE) and a PCR test at the importer. Additional system costs of testing for non-GM and GM segregations are defined as:

$$C_{NGM} = \sum_{\mu=1}^{n} \sum_{r=.005}^{p} T_{\mu r} \cdot TC_{\mu r} \cdot S_{\mu r} \cdot V_{NGM\,\mu r} \tag{1}$$

$$C_{GM} = 0, \tag{2}$$

where C_{NGM} is the additional testing cost accrued to maintain GM separation for non-GM shipments, C_{GM} is the additional handling cost for GM bushels and assumed at nil [implicitly assuming there is adequate capacity to handle increased segregations (Herrman et al., 2002)], μ is the location within the system at which tests can be applied (CE receiving, CE loading, EE receiving, EE loading, importer receiving, domestic user receiving), $T_{\mu r}$ is a binary choice variable reflecting whether tests are applied at location μ for tolerance r, $TC_{\mu r}$ is the cost of individual test for location μ and tolerance r which is mapped directly from the choice of tolerance r at location μ , $S_{\mu r}$ is the sampling intensity (number of samples per lot) at location μ for tolerance r, and $V_{NGM\mu r}$ is the volume (number of lots) of non-GM handled at location μ for tolerance r.

The cost of quality loss is incurred where ownership changes. The loss comprises costs incurred by the shipper and the end user. The shipper is exposed to rejection cost, loss of future business, etc., while the end user is exposed to quality risks (Ross, 1996). Thus, the buyer specifies an acceptable limit to assess quality deviations and the shipper tests to reduce quality loss. Deviations from the target value (in this case, zero GM content in the non-GM flow) represent an implicit cost to the system. Shipments containing lower lot concentrations incur smaller quality loss and vice versa; those with greater deviations increase the risk and cost of rejection. Adding the asymmetric Taguchi loss function to Eq. (1) results in additional system costs for the non-GM flow of:

$$C_{NGM} = \sum_{\mu=1}^{n} \sum_{r=.005}^{p} (T_{\mu r} \cdot TC_{\mu r} \cdot S_{\mu r} \cdot V_{NGM\,\mu r}) + \left(\frac{A_o}{\Delta_o^2} \cdot s^2\right), \tag{3}$$

where C_{NGM} is the additional testing and quality loss cost added to non-GM shipments to maintain GM separation, $\Delta_o$is the buyer upper tolerance limit, A_O is the quality cost at the upper tolerance limit, s^2 is the average lot variance for the distribution of GM lot concentration at change of ownership points from a target value of zero.

The objective function contains a von-Neumann-Morgenstern type utility function, with decreasing absolute risk aversion and increasing relative risk aversion. The Expo-Power Utility (Saha, 1993) is used to measure the risk premium. The model chooses the optimal testing strategy (where to test, intensity, and tolerance) that maximizes expected utility by minimizing the disutility of additional system costs (defined below) for a supply chain handling a portfolio of segregations (non-GM and GM). The portfolio utility for the vertically integrated firm comprises the weighted disutility of additional system costs (testing and quality loss) for handling both segregations. The objective function is:

$$MaxE(U) = Min \sum_{i=1}^{2} \delta_i \cdot DU(C_i) = Min \sum_{i=1}^{2} \delta_i \left(\lambda - e^{(-\phi C_i^{\eta})}\right)$$

s.t.

$$\mathbf{X}\{\mathbf{T_{ur}}, \mathbf{TC_{ur}}, \mathbf{S_{ur}}\} \in \mathbf{K}, \tag{4}$$

where E(U) is the expected value of weighted portfolio utility, $\boldsymbol{\delta_i}$ is the proportion of flows devoted to each segregation ($i =$ non-GM and GM segregations), DU is disutility of additional costs (C_i) for segregation i within the dual handling system, $\boldsymbol{C_i}$ is the additional system cost associated with each segregation ($i =$ NGM, GM as noted in Eqs. (2) and (3)), e is the base of the natural logarithm, λ is a parameter that determines positiveness of the utility function, φ and η are parameters which affect the absolute and relative risk aversion of the utility function, $\boldsymbol{K}$ is the opportunity set of model, and $\boldsymbol{X}$ is a vector of decision variables for the model whose elements include $\mathbf{T_{ur}}$ (whether to test or not at location u at tolerance r), $\mathbf{TC_{ur}}$ (the cost per test at location u for test tolerance r which is mapped directly from the choice of tolerance r at location u), and $\mathbf{S_{ur}}$ (how intensively to test at location u in the grain handling system for tolerance r).

The risk premium is derived by comparing the expected value of a single non-GM (NGM) system with the certainty equivalent for the simulated dual (GM/NGM) marketing system. The risk premium is compensation required by the shipper to be indifferent to the potential additional risks of the dual system. The additional risk premium is derived as:

$$\pi_{GM/NGM} = EV_{NGM} - \hat{C}_{GM/NGM}, \tag{5}$$

where

$$U(\hat{C})_{GM/NGM} = EU(C)_{GM/NGM} = E\left(\sum_{i=1}^{2} \delta_i (\lambda - e^{(-\phi \hat{C}_i^{\eta})}\right), \tag{6}$$

$\pi_{GM/NGM}$ is the additional risk premium for the dual system, EV_{NGM} is the expected value of additional costs of a single non-GM system assumed to be zero, $\hat{C}$ is the certainty equivalent of additional system costs for the dual system, and other parameters are as previously defined.

The risk premium, testing cost, and quality loss constitute the total additional cost required to operate a dual marketing system over a non-GM system. Direct costs are those for testing. Indirect costs are for quality loss incurred at any deviation above the target value and the additional risk premium. Parameters of the utility function are λ, φ, and η, and the values used in the base case are the same as used by Saha (1993). A value of $\lambda = 2$ guarantees positiveness of the utility function. Since the objective function is more sensitive to η than φ, the parameter φ is fixed at 0.01 and for the base case η is set at 0.5. Sensitivities are conducted with values reflecting higher and lower risk aversion. Thus, λ and φ are fixed and sensitivities are conducted about η.

3.1. *Model parameters and solution algorithm*

The model represents the flow of grain through the system. Growers produce GM and non-GM wheat and know its content subject to uncertainty. The grain enters the elevator system at which point it may or may not be declared as having GM and may or may not be tested with a chosen intensity and tolerance. Based on this information, grain is segregated, stored, and may be tested using different types of tests at different tolerances, each at different costs, loaded in railcars, and shipped to EEs where it may be tested upon receipt and/or loading. Results of tests are used to divert lots from the non-GM flow that are identified as GM, to the GM flow. Finally, the wheat is tested at import for GM content subject to the buyer tolerance. If GM content is found, it is diverted subject to a penalty. Since testing involves costs and risks, the model chooses the optimal testing strategy.

Many of the variables in the model are random, the distributions of which are inferred from other studies. Some are represented as triangular distributions where parameters reflect the minimum, most likely, and maximum of values (Table 1). Uncertainty exists at the grower level due to adventitious presence in seed, pollen-mediated gene flow, volunteers, and inadequate sanitation and segregation. The distribution for farm-level adventitious commingling is derived from other studies inclusive of volunteers and pollen-drift (Leeson and Thomas, 2000; Matus-Cadiz et al., 2004; Van Acker et al., 2003), and other factors (Hurburgh, 1999). The risk of adventitious commingling within the handling system is taken from Ingles et al. (2003) and applied at the country and EE.

The risk of adventitious commingling is incorporated at the CE using experience derived from Starlink corn (Environmental Protection Agency, 2003). In that case, commingling was equal to 300% of the Starlink volume introduced into the marketing system. Since we are unaware of the existence of other data on potential rates of commingling due to nondetection or errant truth telling in wheat, this same proportion of adventitious commingling is assumed for the volume of unidentified GM entering the non-GM flow.

Table 1
Base case distributions for adventitious commingling and variety declaration

Location	Distribution	Minimum	Most likely	Maximum
Adventitious commingling				
Grower risk	Triangular	0.01	0.025	0.05
Country elevator	Triangular			
Receiving		0.001	0.01	0.02
Loading		0.001	0.01	0.025
Export elevator	Triangular			
Receiving		0.001	0.01	0.025
Loading		0.001	0.01	0.025
Variety declaration				
No variety declaration (base case)				
Farmer	NA	0	0	0
Country elevator	Triangular	0.95	0.99	1
Export elevator	Triangular	0.98	0.99	1
Variety declaration				
Farmer	Triangular	0.8	0.95	1
Country elevator	Triangular	0.95	0.99	1
Export elevator	Triangular	0.98	0.99	1

Sources: Derived from distributions presented in Hurburgh, 1999; Ingles et al., 2003; and Matus-Cadiz et al., 2004, for grower risk; Ingles et al., 2003, for shipping/handling risk; and Wilson and Dahl, 2005, for variety declaration.

Variety declaration is a mechanism whereby farmers and merchandisers indicate known GM-content at the time of delivery. It has evolved to be a common commercial practice in many non-GM crops involving IP mechanisms and has been used in intra-EU marketing for many years. It will also comprise a key component of the traceability systems in the EU for marketing of GM grains and oilseed that have regulatory approval (Directorate-General, Commission for the European Communities, 2000; Harl, 2001). However, there is risk in variety declaration in that growers may be untruthful and/or be subject to some uncertainty due to pollination drift, volunteers, and segregation risks, each of which raises on-farm costs.

Variety declaration infers a contractual relationship or protocol and/or elevator-imposed mechanisms governing farmer deliveries. In the EU schemes, farmers have an incentive to be truthful so as to not lose their certification in some of the assurance schemes. Estimates of truth telling were elicited in a survey of market participants knowledgeable on GM corn and soybean marketing (Wilson and Dahl, 2005). The results are used to derive a distribution for variety declaration which represents the probability that farmers are truthful when delivering grain and declaring GM content (see lower portion of Table 1). These distributions could alternatively be interpreted as the probabilities of the confidence of a third-party traceability firm acting as an independent agent for the seller or buyer in a transaction to conform to traceability requirements.

Testing and sampling risks are represented by hypergeometric distributions with parameters reflecting lot sizes, sample sizes, and defectives to simulate buyer and seller risks at functions where tests were conducted. These values are taken from current industry practices. Testing costs, accuracy, and tolerances are taken from Strategic Diagnostics, Inc. (2003) for strip tests, and Midwest Seed Services (2002) for PCR tests.

The choice of a test is influenced by its cost, accuracy, and tolerance. Binomial distribution functions are utilized at locations within the marketing chain where testing occurs to determine the probability of rejecting lots based upon incoming GM lot concentration in the non-GM flow, and the simulated tolerance at each location. The probability of rejecting a lot is defined as: $P_{REJECT} = 1 - P_{ACCEPT}$, and potential grain rejection equals: $NGM_{AP} \cdot P_{REJECT}$ which defines defective units. These are used in the hypergeometric distributions where testing is conducted and determine the volume of grain rejected and diverted from the non-GM to GM flow. Through the selection of a tolerance, the model selects the corresponding test accuracy.

Quality loss is a cost when deviating from the target value. The penalty, A_O, is applied at the upper GM tolerance limit and is uniformly distributed with a range of 40–90 c/bu in the export market. This penalty range identifies a best/worse case scenario through two cost components: discounted grain, and logistical costs. Discounts for GM in non-GM corn are historically 10% of the value, which is approximately 40 c/bu in the case of wheat. In addition, rejection may require diverting the shipment to another market, which is 50 c/bu in many geographic international locations. Ultimately, contract specifications govern testing protocols and penalties sustained by the buyer and seller, and these are posed as likely base case scenarios. Additional penalties at intermediate points may be incurred due to re-elevation charges or grain transfers among nonintegrated firms.

The optimal solution defines the testing strategy (where to test, intensity, and tolerance) for intermediate points (CE, EE) all of which are discrete decisions, subject to defined specifications. Tests may be applied at a CE when receiving and loading, and at the EE when receiving and loading; however, they are required at the importer. Test intensity is 1:1 (test every lot) at the importer, but may vary from 1:1 to 1:5 (test every fifth lot) at intermediate points. Test tolerance for PCR and strip testing can be applied from 0.04% to 5% at intermediate points, but is predefined at the importer with a base case of 1%.

3.2. Simulation/optimization procedures

The specification results in a stochastic optimization model which is solved with *Risk Optimizer,* a genetic algorithm-based optimization program designed to optimize models containing uncertainty (Palisade Corporation, 1998). Probability distribution functions are used to define risk for the random variables. The objective function minimizes the weighted disutility of additional system costs by determining locations where tests are applied, test intensities and tolerances at the CE receiving/loading and EE receiving/loading locations. Testing decisions are discrete choice variables at each location representing whether tests are conducted (Yes = 1, No = 0); test intensities specify the frequency at which the test is applied at each location (1:1, 1:2, 1:3, 1:4, and 1:5 indicate testing of 1 unit out of X units); and tolerances (0.04% to 5%) determine the cost of the test applied at each location. *Risk Optimizer* runs a full simulation for each potential trial solution. Each iteration of a trial solution's simulation samples probability distribution functions to generate a new objective value. One thousand iterations are performed successively until no improvement in the objective value has been found for a significant period of time.

4. Results and sensitivities

4.1. Base case

A base case is defined to reflect a likely system and protocols for a dual marketing system. These include: GM adoption of 20% by farmers; no variety declaration of GM content at CE; adventitious commingling risk due to the inability to distinguish GM content through variety declaration is 300% of the volume of unidentified GM delivered at the CE; testing can be done at the CE receiving/loading and EE receiving/loading; the importer's specification limit on GM content in non-GM grain is 1% and the penalty at the importer's specification limit is uniformly distributed from 40 to 90 c/bu.

The suppliers' optimal strategy (Table 2) is to conduct one test per two truckloads at a 4% tolerance at the CE when receiving, test every railcar at the CE when loading at a 0.5% tolerance, and test every shiphold at the EE when loading at a 0.5% tolerance. Each of these differs from the buyers' tolerance specification due to their costs and risks. The sellers' risk is the average rejection of non-GM bushels (2.83%). The buyers' risk is 0.000154% and represents the portion of lots containing adventitious presence exceeding importer specifications for GM content in non-GM grains in the importer flow after testing. The proportion of flows in the non-GM channel decline from 80% at the farm level to 48% at the importer, due to the diversion of non-GM lots containing adventitious presence of GM. This indicates that 32% of wheat that was grown as non-GM is diverted to the GM channel.

The utility equates to a certainty equivalent of 2.4 c/bu. This represents the premium required by the shipper to be indifferent between the dual non-GM/GM system with its accompanying test strategy (locations, intensities, tolerances) and a non-GM system. It reflects the value of the additional risk incurred in a dual marketing system through handling GM and marketing non-GM.

Costs of testing and quality loss are 5.2 c/bu, comprising inbound and outbound testing at CE of 0.2 c/bu and 0.08 c/bu; testing at EE loading of 0.006 c/bu; testing every hold at the importer of 0.38 c/bu; and quality loss of 4.5 c/bu. In conjunction with the risk premium, total costs are 7.6 c/bu averaged over all bushels and 16 c/bu when averaged over GM bushels. The distribution of additional system costs indicates a 5% probability

Table 2
Base case results and sensitivities to risk aversion (η) and variety declaration

	Base case	Risk aversion		Variety declaration	
Risk aversion	0.5	Less risk	More risk		
Variety declaration	None	Averse	Averse	40-50-60%	80-95-100%
Utility	1.0145	1.0112	1.0281	1.0144	1.0139
Optimal strategy					
Test (1 = yes, 0 = no)-Intensity (test every *X*th unit)-tolerance (test tolerance in percent)*					
Country elevator receiving	1-2-4	0-NA-NA	1-1-0.5	1-2-3	0-NA-NA
Country elevator loading	1-1-0.5	1-1-0.5	1-5-5	1-2-5	1-5-3
Export elevator receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export elevator loading	1-1-0.5	1-1-0.75	1-1-0.75	1-1-4	1-1-1
Probabilities (in percent)					
GM in importer flows (buyer risk)	0.000154	0.000367	0.000137	0.000120	0.000092
Rejection at importer (seller risk)	2.83	4.55	1.76	2.53	2.15
Costs (c/bu)					
Testing/all bu	0.7	0.3	1.0	0.7	0.5
Quality loss/all bu	4.5	10.6	2.4	3.8	3.1
Certainty equivalent (premium)	2.4	1.6	3.3	2.3	2.2
Total/all bu	7.6	12.5	6.7	6.8	5.8
Total/non-GM bu	15.8	43.3	9.2	12.6	9.3
Percentage of non-GM flow by location					
Adoption rate	80	80	80	80	80
Country elevator received	78	100	78	78	82
Country elevator loaded	51	31	78	63	72
Export elevator received	52	33	78	63	73
Export elevator loaded	49	30	74	55	64
Importer received	48	29	73	54	63

*When tests are not applied at a location (Test = 0), sampling intensity and tolerance are not applicable (NA).

of total costs being less than 4 c/bu, and a 95% probability of them being less than 39 c/bu.

4.2. Relative risk aversion (η)

Sensitivities are conducted on risk aversion to illustrate the tradeoff between testing cost and quality loss. Two cases were specified and the optimal testing strategy, risks, and costs are contrasted with the base case ($\eta = 0.5$) (Table 2). Optimal testing strategies intensify from the less risk-averse to the more risk-averse case. Testing for the less risk-averse case is conducted on every outbound unit at country and EE loading locations at a 0.5% and 0.75% tolerance, respectively. More risk-averse shippers would test every unit at CEs receiving at a 0.5% tolerance, every 5th unit at CE loading at a 5% tolerance, and every unit at EE loading at a 0.75% tolerance. The increase in risk aversion results in an increased propensity to avoid quality loss uncertainty. With a higher risk aversion, the risk premium is 3.3 c/bu, but it decreases to 1.6 c/bu when risk aversion is lower. More risk-averse shippers discount additional testing cost and quality loss more than less averse shippers and, consequently, require a higher premium to participate in a dual marketing system.

4.3. Variety declaration

The base case scenario precludes a mechanism to elicit information from growers regarding the GM content of their grains. Contracts according to which growers declare deliveries as either non-GM or GM would facilitate segregation at the point of first receipt. Two models utilizing alternative distributions of truthfulness were developed to examine the effect on system costs and risks. The alternative distributions for truth telling are triangular distributions of: [0.40, 0.50, 0.60] and [0.80, 0.95, 1.00].

The optimal testing strategy is less intensive as farmer truth telling increases (Table 2). The low variety declaration model tested every other unit at CE receiving and loading at a 3% and 5% tolerance, respectively, and every unit at EE loading at a 4% tolerance. The high variety declaration model tested every 5th unit at CE loading at a 3% tolerance, and every unit at EE loading at a 1% tolerance. Thus, shippers can substitute information from variety declaration for testing. Total costs for all bushels decrease from 7.6 c/bu in the base case to 6.8 c/bu for the low variety declaration model and 5.8 c/bu for the high variety declaration model.

4.4. Import specification of tolerances for GM content in non-GM grains

In the base case, the buyers' tolerance of GM content in non-GM lots is 1%. This approximates the anticipated (at the time) EU limits, which have now been defined at 0.9%. Tolerances will vary across importers depending on regulatory mandates, labeling requirements, end user quality specifications, competition, and commercial firm strategies. Import specifications on GM content in non-GM grains are changed to quantify additional system costs arising from each respective optimal strategy. Five cases are specified with maximum importer specification limits on GM content of 0.5%, 2%, 3%, 4%, and 5%. The range is inclusive of anticipated industry practices; while the EU has set a level of 0.9% of all food and feed containing GM, other countries such as Japan, Taiwan, Thailand, Hong Kong, etc. would likely require a 5% specification limit, and numerous countries mandate limits on GM content in non-GM grains between 0.5% and 5% (Chuen, 2003; Smyth and Phillips, 2001).

The optimal testing strategy becomes less intensive as import specifications on GM content are loosened from 0.5% to 5% (Table 3). Testing is similar to the base case for a 0.5% import specification with the exception of test tolerances. Testing is conducted on every unit at CE receiving at a 1% tolerance, every 5th unit at CE loading at a 5% tolerance, and every unit at EE loading at a 0.5% tolerance. In contrast, the optimal testing strategies for specifications looser than the base case do not include testing at the CE when receiving. No testing at the CE when receiving exacerbates the adventitious presence of GM within the non-GM flow, primarily due to the high rates of adventitious commingling associated with the volume of unidentified GM lots entering the non-GM flow. The percent of non-GM flows at the importer significantly declines as import specifications are loosened from 2% to 5%. Relative to the base case, the probability of rejection by the importer decreases for the 0.5% case and increases for the 2%, 3%, 4%, and 5% cases. Thus, with looser importer specifications for GM content in non-GM grains, the impacts of quality loss costs are less for a given deviation and, as such, testing provides less benefits to shippers who would tend to test less. Since the impact of quality loss costs is less, shippers incur less testing cost and tolerate higher rejection rates. GM content in importer flows of non-GM grains is negligible in all cases.

The risk premium is 7.7 c/bu for a 0.5% import specification, but declines to 0.2 c/bu for a 5% import specification. Relative to the base case, non-GM testing costs increase for the 0.5% import specification limit, and decrease for the other cases. This is illustrative of reduced nonconformance risk as buyer specifications are loosened. Quality loss and total costs decrease as buyer specifications are loosened except at a 4% import specification, where cost slightly increases due to a different strategy being employed that trades off a decrease in testing cost for an increase in quality loss.

4.5. GM adoption and the ability to conform to specifications

The level of GM adoption will vary geographically and through time, and this affects strategies, costs, and risks. The base case assumes a 20% GM adoption rate. To illustrate the impact of different adoption rates, the model was simulated with rates ranging from 10% to 70%. Each was simulated first assuming no variety declaration, and then assuming that a variety declaration system was used.

Table 3
Sensitivities to importer tolerance specification

Tolerance (in percent)	0.5	Base case 1	2	3	4	5
Utility	1.0253	1.0145	1.0086	1.0060	1.0052	1.0044
Optimal strategy						
Test (1 = yes, 0 = no)-intensity (test every *X*th unit)-tolerance (test tolerance in %)*						
Country elevator receiving	1-1-1	1-2-4	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Country elevator loading	1-5-5	1-1-0.5	1-1-1	1-1-2	1-2-0.5	1-2-1
Export elevator receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export elevator loading	1-1-0.5	1-1-0.5	1-1-2	1-1-2	1-1-4	1-1-1
Probabilities (in percent)						
GM in importer flows (buyer risk)	0.000108	0.000154	0.000364	0.000152	0.000564	0.000341
Rejection at importer (seller risk)	1.93	2.83	4.35	3.84	6.07	5.43
Costs (c/bu)						
Testing/all bu	1.0	0.7	0.3	0.3	0.2	0.2
Quality loss/all bu	9.6	4.5	2.6	1.2	1.5	0.9
Certainty equivalent (premium)	7.7	2.4	0.8	0.4	0.3	0.2
Total/all bu	18.3	7.6	3.8	2.0	2.0	1.4
Total/non-GM bu	25.2	15.8	13.2	6.7	10.5	7.2
Percentage of non-GM flow by location						
Adoption rate	80	80	80	80	80	80
Country elevator received	78	78	100	100	100	100
Country elevator loaded	78	51	31	31	31	31
Export elevator received	78	52	33	33	33	33
Export elevator loaded	74	49	30	30	20	20
Importer received	73	48	29	29	19	19

*When tests are not applied at a location (Test = 0), sampling intensity and tolerance are not applicable (NA).

As adoption increases, there is more intensive testing throughout the system, costs increase, and rejection rates increase, resulting in greater seller risk. For the no variety declaration case, the results indicate that it would be infeasible to effectively segregate at a 30% adoption rate. This occurs because the effects of commingling of adventitious presence are such that limited volume, if any, can be delivered to the end user as non-GM at the base case 1% buyer tolerance. Further, since costs per non-GM bushel are in the objective function and as the proportion of flows to the end user that are non-GM approaches zero, costs approach infinity.

If variety declaration is adopted, the results are feasible up to the 70% adoption rate. At that point, costs escalate radically and the system becomes infeasible. As above, as adoption increases, there are increases in testing intensity, costs, risk premiums, and rejection rates. Rejection rates increase from 2.83% in the base case to 4.87% at 70% adoption. Total costs increase due to an increase in quality loss, testing, and a greater risk premium as adoption increases. Total system costs increase from the base case to 7.7, 10.3, and 15.6 c/bu at the 50%, 60%, and 70% adoption rates, respectively.

5. Conclusions and implications

The objective of this article was to evaluate testing and segregation strategies for a dual marketing system consisting of non-GM and GM flows. A stochastic optimization model was constructed utilizing an objective function that maximizes portfolio utility or equivalently minimizes portfolio disutility of additional system costs for handling both non-GM and GM wheats. The contribution of this article to the evolving literature on marketing GM crops is that it develops a methodology that determines the suppliers' optimal testing and tolerance strategy to conform to the buyers' specifications. Specifically, it allows for the simultaneous decision of testing technology and intensity. It also quantifies the system cost, risk premiums, buyer and seller risks, and illustrates the prospective impact of tighter tolerances on these costs and risks.

The results indicate that with reasonable assumptions about base case parameters, non-GM grain can be marketed concurrently with the existence of GM grains. The model is used to quantify changes in costs and buyer and seller risks associated with different underlying assumptions. Optimal strategies are influenced by several factors. First, increasing shipper risk aversion results in more intensive testing strategies and requires a greater risk premium for shippers. Second, loosening buyer specifications results in optimal strategies that test less intensively, at fewer locations and at lower tolerances, and have reduced costs and risk premiums. Third, use of variety declaration systems, which elicit information from growers about GM content in their deliveries, reduces costs and risks. Further, the importance of variety declaration increases as GM adoption rates increase. Without variety declaration, the system is unable to effectively segregate at 30% adoption rates. With variety declaration, the system is able to segregate, albeit at higher costs, for GM adoption rates up to 70%.

Commercialization of GM crops challenges the functions and operations of the grain marketing system. There is a high degree of variability with respect to aversion by buyers for GM wheat. While there is strong opposition in the EU, in Japan, in the organic segment, and in a number of other countries, there are a number of markets thought to be more accepting of GM wheat, particularly at a lower cost. This implies that if any GM wheat trait is released, the market system would need a multitude of mechanisms to serve the diverse needs of GM buyers. Results suggest that systems for the organic sector and the EU would be more onerous as they would imply more risk and intervention, whereas many of the less averse segments could be served with less stringent contracts and testing for specification limits. Further, the EU traceability requirements provide some assurance to buyers and consumers about the products' content, which is certainly beyond that which would emanate from the other systems.

The results suggest other implications for the public sector. First, while nil tolerances are unattainable, GM content can reasonably be assured for anticipated import specifications of 1.0% or above. However, these may not provide the types of assurance implied in traceability systems. Second, variety declaration mechanisms are an important element to testing and tolerance strategies. Adding variety declaration allows for segregation at delivery and results in strategies that involve less intensive testing, and lower rejection rates and costs. Variety declaration also allows for feasible testing and tolerance segregation strategies to exist at greater GM adoption rates. Finally, whether the costs of a system based on testing and segregation are lower than alternative comprehensive IP or traceability systems is not clear. Given the latter are more comprehensive, they would likely have greater costs. Indeed, that would be the case by simple comparison with other studies. To offset this, however, IP and traceability could complement a system of testing in that through protocols the risks throughout the system might be reduced, which would reduce some of the costs.

There are several private sector implications. First, suppliers have choices in determining their strategies, which can be done with relatively low cost and risk. Second, there is seller risk which will vary across countries and which should be captured in their margins. Finally, alternatives to testing and segregation include IP and traceability systems, which are demanded for transactions in some countries, notably in the EU. These systems may encompass testing and segregation, in addition to other restrictions on transactions and information flow.

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